The Doppler Effect

A radar detects the presence of objects and locates their position in the space by transmitting EM energy and observing the return echo. Presence of echo not only indicates the presence of target, but the time that elapses b/w transmission of pulse and the receipt of the echo is a measure of the distance to the target. Sepration of the echo signal and transmitted signal is made on the basis of the difference time.

It is well known in the fields optics and acoustics that if either the source of oscillation or the observer of the oscillations is in motion, an apparent shift in frequency will result. This is the Doppler effect and basis of CW radar.

$R \rightarrow$ Distance b/w target & radar

$\Rightarrow \frac{2R}{\lambda}$ No. of wavelengths λ covered (contained) in the two way path b/w radar and target.

one wavelength corrosponds to an angular excursion of 2π radian, $\Rightarrow$ total excursion made by wave during it transmit to and from the target $\Rightarrow \frac{4\pi R}{\lambda} = \phi$ (Total excursion)

if the target is in motion R and phase ϕ continually changing. In change in ϕ w.r.t time equal to frequency. This is the doppler angular frequency w_d.

$$w_d = 2\pi f_d = \frac{d\phi}{dt} = \frac{4\pi}{\lambda}\frac{dR}{dt} = \frac{4\pi V_r}{\lambda} \quad - ①$$

$f_d \rightarrow$ doppler frequency shift

$V_r \rightarrow$ relative (or radial) velocity of target w.r.t radar.

$$\Rightarrow f_d = \frac{2V_r}{\lambda} = \frac{2V_r f_0}{C}$$

$f_0 \rightarrow$ transmiter frequency

$$\Rightarrow f_d = \frac{1.03\, V_r}{\lambda}$$

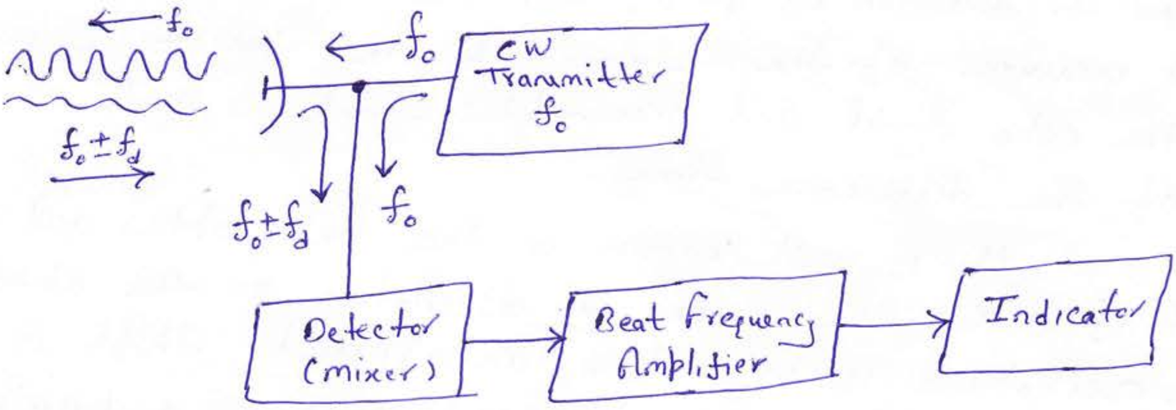
relative velocity can be written as $V_r = V \cos\theta$

$V \rightarrow$ target speed and θ angle made by target trajectory and

the line joining radar and target.
When θ=0 doppler frequency is maximum.

CW Radar: →

CW stands for continuous ~~radar~~ wave radar.



(Simple CW Radar)

~~Tran~~ Transmitter generates a unmodulated wave of frequency f_0, which is radiated by antenna. if the target is in motion with a velocity v_r, relative to radar, the received signal will be shifted in frequency from the transmitted frequency f_0. the purpose of doppler amplifier is to eliminate echoes from stationary targets and to amplify the doppler echoes signal to a level where it can operate an indicating device. the indicator might be a pair of earphones or a frequency meter.

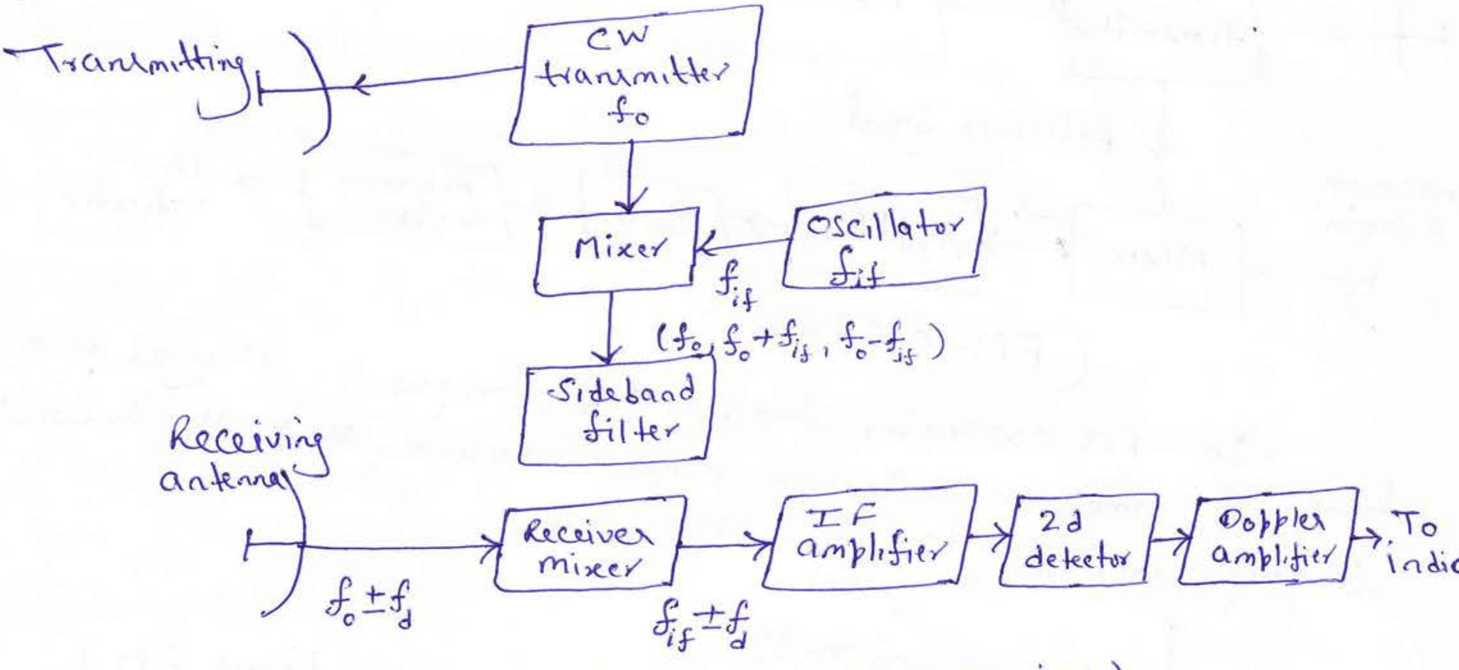
isolation b/w transmitter and receiver — A single antenna serves the purpose of transmission and reception in the simple CW radar. The necessary isolation b/w the transmitter and receiver is achieved via separation in the frequency as a result of doppler effect.

The amount of isolation required depends on the transmitter power and the accompanying transmitter noise ~~and~~ (as well as) the sensitivity of the receiver.

Intermediate - Frequency Receiver

Flicker noise is the main effect which produce distortion in the received signal. Flicker noise occurs in semiconductors such a diode detectors, transistor etc. The noise power produced by flicker effect varies as $1/f$.

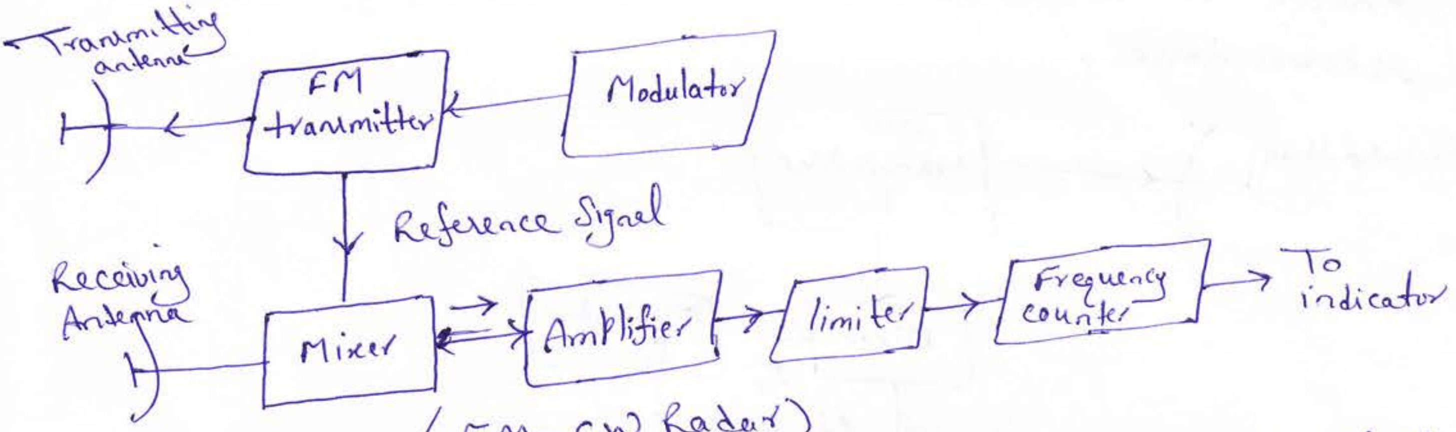
The effect of flicker noise are overcome in normal superhydrodyne receiver by using an intermediate frequency hi enough to render flicker noise small as compare to norm receiver noise.



(CW radar with nonzero IF receiver)

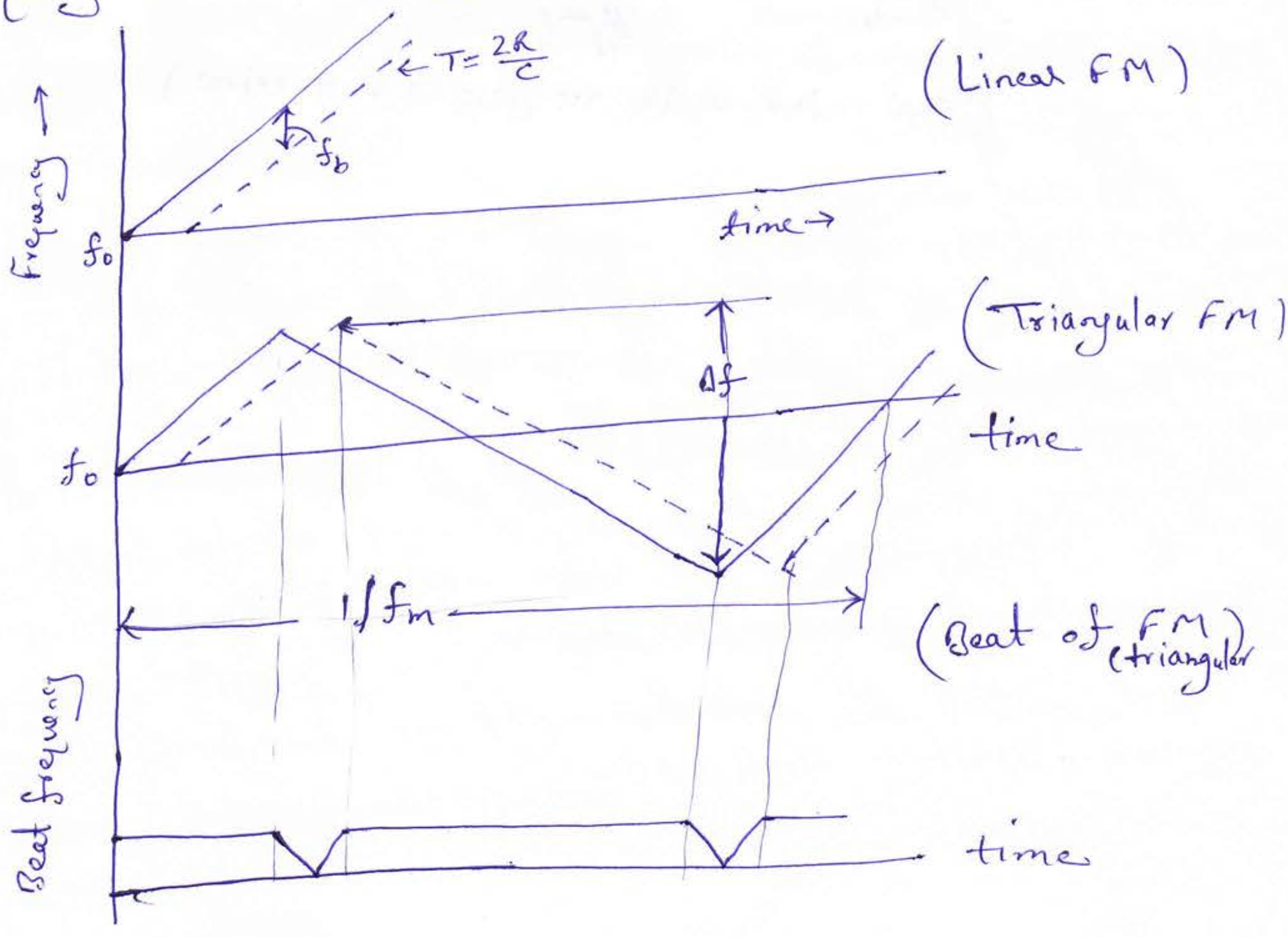
FM-CW Radar: (Frequency Modulated) CW Radar:—

The inability of a simple CW radar to measure range is related to the relatively narrow spectrum (B.W) of its transmitted waveform. Some sort of timing mark must be applied to CW carrier if range is to be measured. The timming mark permits the time of transmission and the time of return to be recognised. The sharper or more distinct the mark, the more accurate the measurement of transit time.



(FM-CW Radar)

In FM-CW radar transmitter frequency changed as a funct^n of time in a known manner assume that the transmitter frequency increase linearly with time



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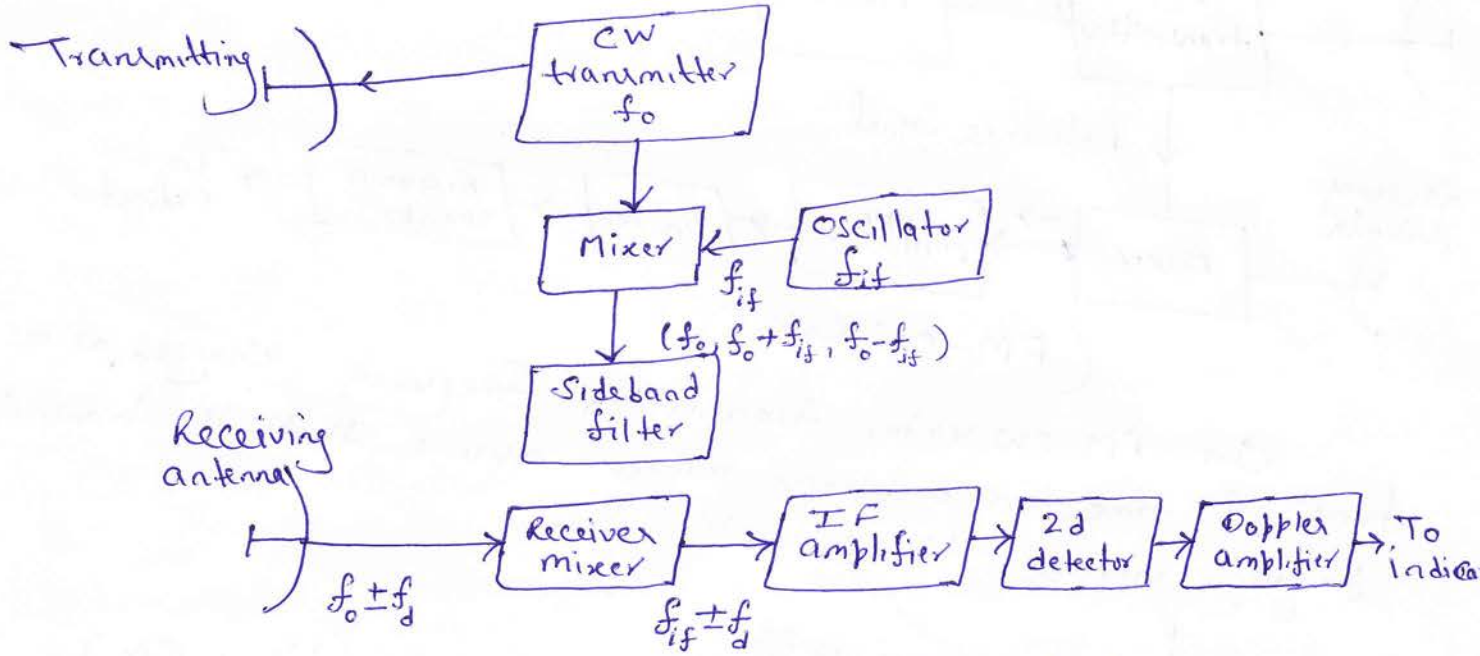
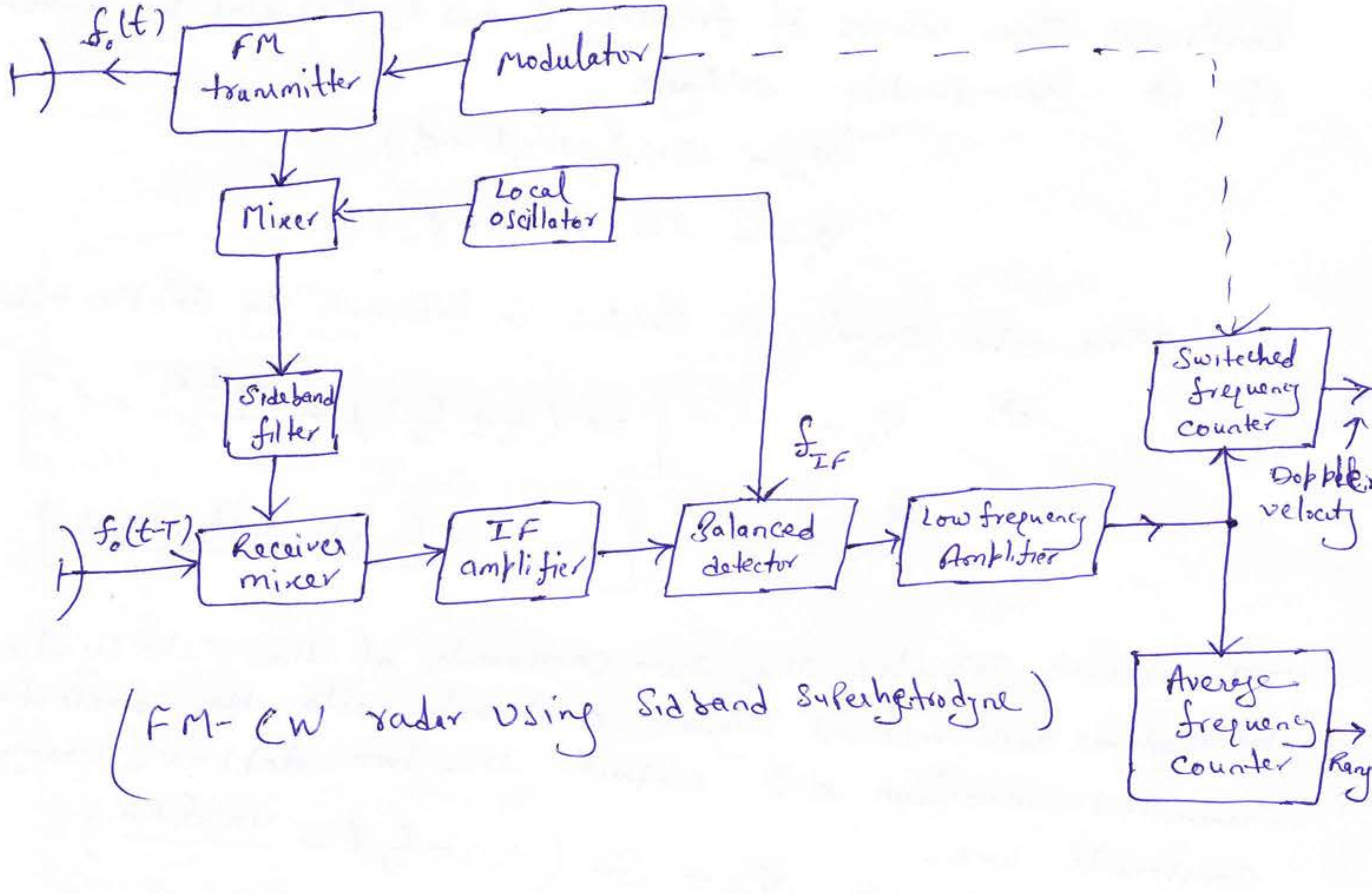


(CW radar with nonzero IF receiver)

FM-CW altimeter :— The FM-CW radar pricible is used in aircraft radio altimeter to measure height above the surface of each. The large backscatter cross section and the relative short ranges required of altimeters permit low transmitter power and low antenna gain.



(FM-CW radar using Sidband Superhetrodyne)

MULTIPLE FREQUENCY CW RADAR:—

CW radar does not measure range, it is possible under some circumstances to do so by measuring the phase of the echo signal relative to the phase of transmitted signal.

Consider a CW radar radiating a single frequency sine wave of form $\sin 2\pi f_o t$. The signal travel to the target at a range R and returns to the radar after a time $T = 2R/c$. The echo signal received at the radar is in $[2\pi f_o(t-T)]$. If the transmitted and received signals are compared in phase detector, the O/P is proportional to the phase difference b/w two and is $\Delta\phi = 2\pi f_o T = 4\pi f_o R/c$.

The phase difference may therefore be used as a measure of the range, or $R = \frac{c\Delta\phi}{4\pi f_0} = \frac{\lambda}{4\pi}\Delta\phi$ — ①

When put $\Delta\phi = 2\pi$ into ① gives the maximum unambig-ous range as $\lambda/2$.

The transmitted waveform is assumed to consist of two continuous sine waves of frequency f_1 and f_2 seprated by amount Δf. ⇒ corresponding voltages

$$v_{1T} = \sin(2\pi f_1 t + \phi_1)$$

$$v_{2T} = \sin(2\pi f_2 t + \phi_2)$$

The echo signal is shifted in frequency by doppler effect

$$\Rightarrow v_{1R} = \sin\left[2\pi(f_1 \pm f_{d1})t - \frac{4\pi f_1 R_0}{c} + \phi_1\right]$$

$$v_{2R} = \sin\left[2\pi(f_2 \pm f_{d2})t - \frac{4\pi f_2 R_0}{c} + \phi_2\right]$$

The receiver seprates the two components of the echo signal and heterodynes each received signal component with the corresponding transmitted waveform and extract the two doppler frequency components are

$$v_{1D} = \sin\left(\pm 2\pi f_d t - \frac{4\pi f_1 R_0}{c}\right)$$

$$v_{2D} = \sin\left(\pm 2\pi f_d t - \frac{4\pi f_2 R_0}{c}\right)$$

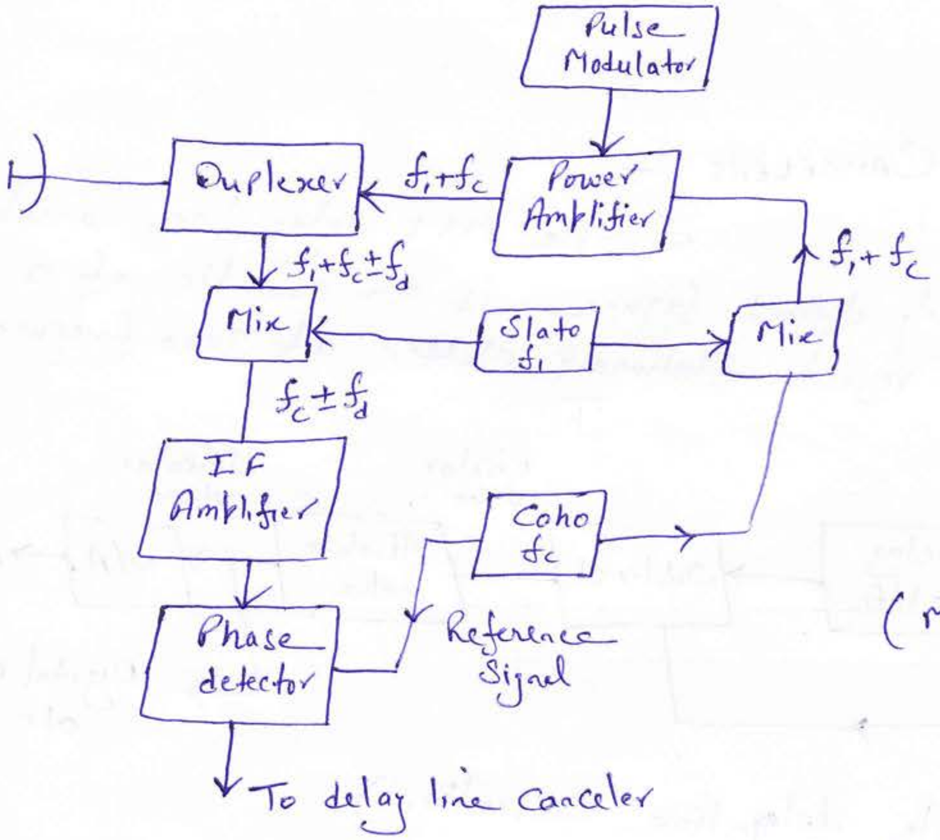
The phase difference b/w two components is

$$\Delta\phi = \frac{4\pi(f_2 - f_1)R_0}{c} = \frac{4\pi\,\Delta f R_0}{c}$$

$$\Rightarrow R_0 = \frac{c\,\Delta\phi}{4\pi\,\Delta f}$$

MTI RADAR AND PULSE DOPPLER RADAR:–

A pulse radar that employs the doppler shift for detecting moving targets is either an MTI (moving target indication) radar or pulse doppler radar. The MTI radar has a pulse repetition frequency (prf) low enough to not have any range ambiguities as in $R_{un} = \frac{cT_p}{2} = \frac{c}{2f}$



(MTI Radar)

The local oscillator of an MTI radar's superhetrodyne receiver must be more stable than the local oscillator for a radar that does not employ doppler. To recognize the need for high stability, the local oscillator of an MTI receiver is called stalo, which stand for stable local oscillator. The IF stage is designed as the matched filter, as is usually the case in radar. Instead of amplitude detector, there is a phase detector following the IF stage. This is a mixer like device that combines the received signal and reference signal from coho. The name coho stands for coherent oscillator to signify that the reference signal that has phase of the transmitter signal.

coherency with the transmitted signal is obtained by using the sum of the coho and the stalo signals as the I/P signal to power amplifier.

The power amplifier is a good transmitter for MTI radar since it can have high stability and is capable of high power. The pulse modulator turns the amplifier on and off to generate the radar pulses.

DELAY-LINE CANCELERS :-

Simple MTI delay line canceler (DLC) of previously defined figure is an example of a time domain filter that rejects stationary clutter at zero frequency.

(Single delay-line Canceller)

The signal from a target at range R_0 at the O/P of the phase detector can be written

$$V_1 = k \sin(2\pi f_d t - \phi_0)$$

we can write delayed version of V_1

$$V_2 = k \sin[2\pi f_d (t - T_p) - \phi_0]$$

$$\Rightarrow \quad V = V_1 - V_2 = 2k \sin(\pi f_d T_b) \cos\left[2\pi f_d\left(t - \frac{T_p}{2}\right) - \phi_0\right]$$

The frequency response funcn of the single delay-line canceler is then

$$H(f) = 2\sin(\pi f_d T_p) \quad \text{—— (1)}$$

Blind Speeds:- The response of the single delay line canceler will be zero whenever the magnitude of $\sin(\pi f_d T_p)$ in (1) is zero.

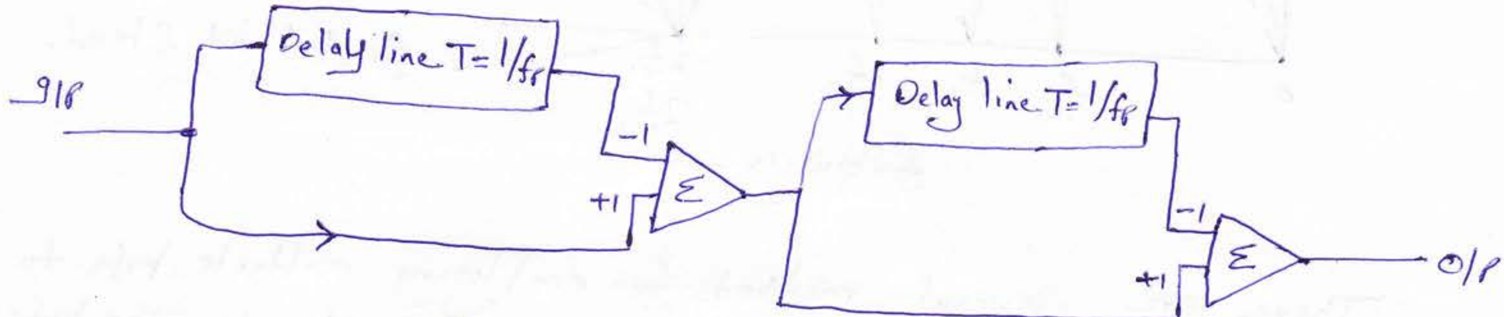
which occurs when $\pi f_d T_p = 0, \pm\pi, \pm 2\pi - -$

$$\Rightarrow f_d = \frac{2v_r}{\lambda} = \frac{n}{T_p} = n f_p \qquad n = 0, 1, 2 - -$$

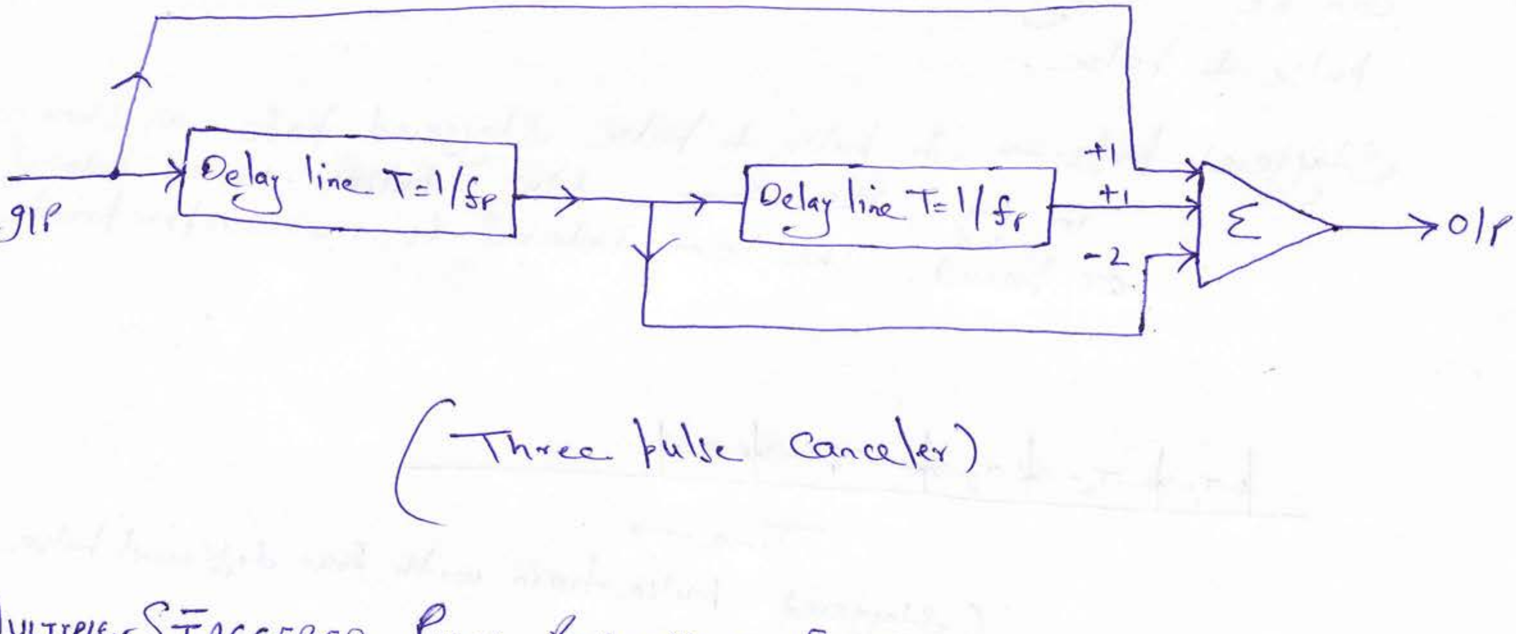
The radial velocities that produce blind speed are

$$v_n = \frac{n\lambda}{2T_p} = \frac{n\lambda f_p}{2} \qquad n = 1, 2, 3 - -$$

where v_r has been replaced by v_n, the n^{th} blind speed.



(Double delay line canceler)

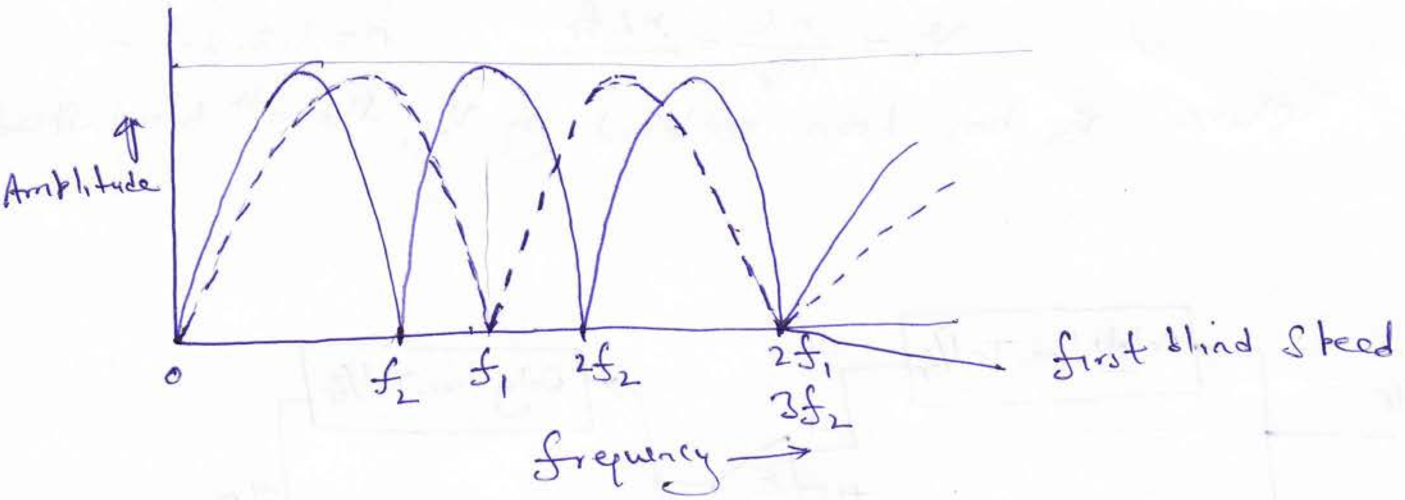


(Three pulse canceler)

MULTIPLE, STAGGERED PULSE REPETITION FREQUENCIES

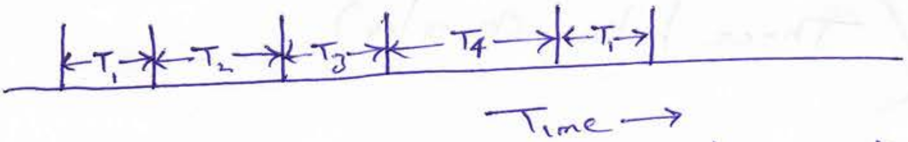
The use of multiple waveforms with different pulse repetition frequencies allow the detection of moving targets that would otherwise be eliminated with a constant-prf waveform if their radial velocities were at, or in vicinity of, a blind speed ($v_n = \frac{n\lambda f_p}{2}$). As shown in figure frequency response of of a single delay line canceler with two different pulse repetition frequencies. At prf f_1

blind speeds (nulls) occur when the doppler frequency is f_1 or $2f_1$. with prf $f_2 = 2f_1/3$ blind speed occur when the doppler frequency equals f_2, $2f_2$ or $3f_2$.



There are several methods for employing multiple prfs to avoid losing target echoes due to blind speeds. The prf can be changed 1) Scan to Scan (2) dwell to dwell (3) pulse to pulse.

Staggered prfs. → In pulse to pulse staggered prfs as shown in fig., the time b/w pulses is an interval or period. The term interval is more appropriate



(Staggered pulse train with four different pulse period)

RANGE GATED DOPPLER FILTERS

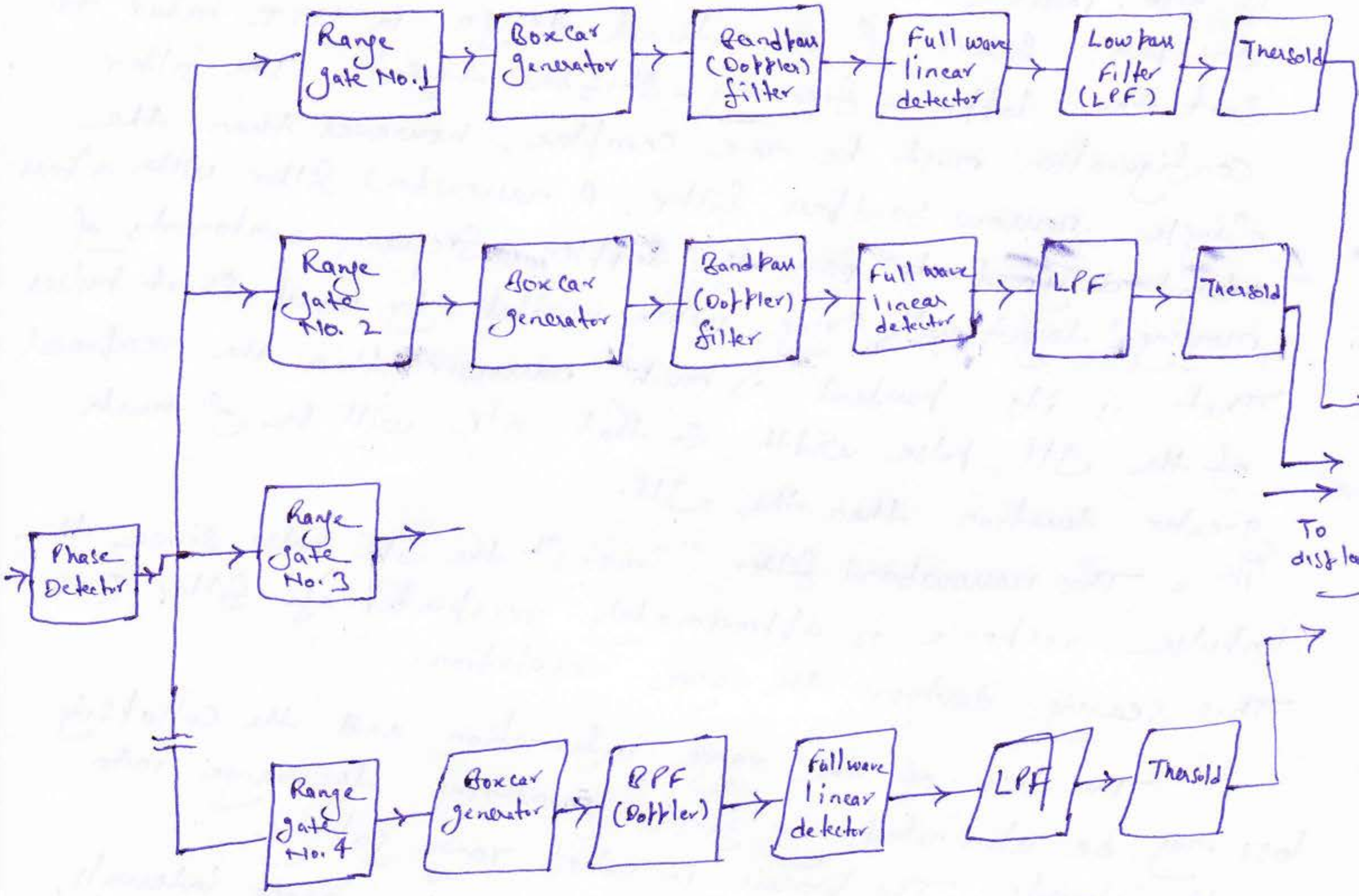
The delay line canceler, which can be considered as a time-domain filter, has widely used in MTI radar as the mean for separating moving targets from stationary clutter. It is also possible to employ the more usual frequency domain bandpass filters of conventional design in MTI radar to sort the doppler-frequency-shifted targets. The filter configuration must be more complex, however than the single narrow bandpass filter. A narrowband filter with a pass-band designed to pass the doppler frequency components of moving target will "ring" when excited by usual short pulse. That is its passband is much narrower than the reciprocal of the I/P pulse width so that O/P will be of much greater duration than the I/P.

The narrowband filter "smears" the I/P pulse since the impulse response is approximately reciprocal of filter B.W. This searing destroys the range resolution.

The loss of the range information and the collapsing loss may be eliminated by first quantizing the range into small intervals. The process is called range gatting. Once the radar return is quantized into range intervals, the O/P from gate may be applied to a narrow band filter since the pulse shape need no longer be preserved for range resolution. A collapsing loss does not take place since noise from other range intervals is excluded.

A block diagram of the video of an MTI radar with multiple range gates followed by clutter-rejection filter shown in Fig. The O/P of phase detector is sampled sequentially by the range gates. Each range gate opens in sequence just long enough to sample range gate acts as a switch or gate which opens and closes at proper time.

An echo from a moving target produces a series of pulses which vary in amplitude according to the doppler frequency.



(MTI radar using range gates and filter)

The O/P of range gates is streched in a ckt called the boxcar generator or sample and hold ckt, whose purpose is to aid in the filtering and detection process ~~and~~ by emphasizing the fundamental of the modulation frequency and eliminate harmonics of prf.

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LIMITATIONS TO MTI PERFORMANCE

The limitations to MTI performance ~~to be~~ cause the clutter spectrum to widen. More clutter energy is then passed by the doppler filter, which lower the improvement factor. if the clutter power spectral density can be expressed as a gaussian funcⁿ with a standard deviation σ_c in H_z, it can be represented by

$$W(f) = W_0 \exp\left(-\frac{f^2}{2\sigma_c^2}\right)$$

Antenna Scanning Modulation:– The frequency spectrum has a B.W inversely proportional to the time duration to. Consequently, even if the clutter scatters were prefectly stationary and there were no instability in the radar equipment, there would still be a finite spectral spread due to the finite duration of echo signal. This is called antenna scanning modulation, this basically due to finite time on target. The longer the time on the target the less will be the spread in the clutter spectrum.

System Instabilities:→ Changes in the amplitude, frequency, or phase of the stalo or coho oscillators as well as changes in the pulse to pulse characteristics of the transmitted signal or error in the timing can result in uncanceled clutter echoes and cause a limit to the improvement factor that can be achieved.

Amplitude Changes:– If the single delay line canceler, has amplitude of the first pulse received from a stationary clutter scatterer is A and the second pulse is A+ΔA, the voltage o/p of the delay-line canceler is ΔA. ⇒ Clutter attenuation $= \frac{(\Delta A)^2}{A^2}$ and the improvement factor is twice of this.

(14)

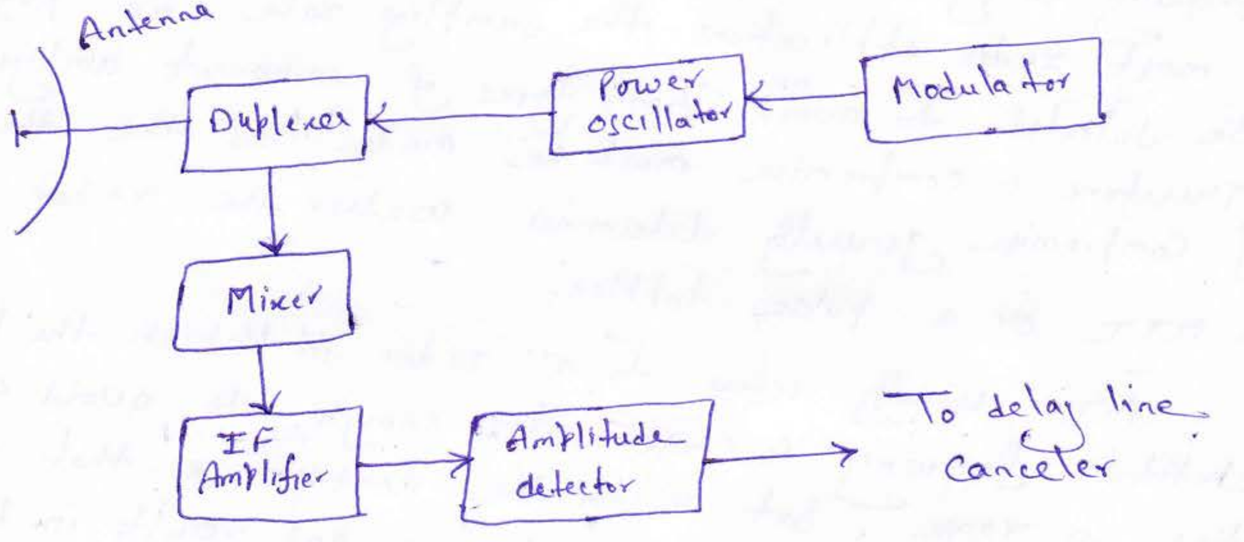
Phase changes:— If the echo received from the first pu[lse] from Stationary Clutter is represented by $A \sin(\omega t + \phi)$ a[nd] if the echo from the second pulse is $A \sin(\omega t + \phi + \Delta\phi)$ there will be an uncanceled residue from a single de[lay] line canceler equal to the difference, $2A \sin(\Delta\phi/2)$, where $\Delta\phi \rightarrow$ phase changes b/w pulses. For small ph[ase] changes, the o/p voltage is $A\Delta\phi$.

Phase Noise:— Noise due to phase fluctuations associat[ed] with the Stalo and coho oscillators can be a major limitation to the improvement factor of high performance MTI radar. Generally, phase noise has a much larger effect than noise caused by amplitude instabi-lities. The phase noise from oscillators in the exciter o[f] a power amplifier affect the transmitted signal as well as the signal in the receiver.

Limiting in MTI Radar:— clutter echoes often can be large enough to saturate the radar receiver, obscure target echoes on a display, and cause false alarm[s]. Saturation of the receiver by the clutter echoes also result[s] in spreading of the clutter spectrum that reduces the improvement factor. if the receiver is of large enough dynamic range, and there are sufficient bits in the A/D converter, and if the improvement factor is large enough to make the uncanceled clutter residue smaller than receiver noise, there will be no problem since there will be no limiting. larger dynamic rang[e] and cancellation of all the large clutter, however, are n[ot] the usual situation. A limiter in the MTI receiver has some times been used to reduce the clutter to the level of receiver noise.

NONCOHERENT MTI

In an MTI radar there must be a reference signal to recognize that the echo signal of a moving target is shifted in frequency by the doppler effect. The echo signal from clutter also has the characteristics of the transmitted signal and can be used as a reference to extract the doppler frequency shift of the target echo signal. Since the clutter echo and the moving target echo appear together at the I/P to the receiver, an internal reference signal is



(Noncoherent MTI radar)

not needed. A radar that uses the clutter echo as the reference signal to extract the doppler-shifted target echo is known as a non coherent MTI radar.

The advantage of non coherent MTI (~~application~~) is its relative simplicity. It was used in the past for both land-based and airborne MTI applications. A limitation is that it requires that clutter echo be presented along with target echo.

PULSE DOPPLER RADAR

Pulse radar that extracts the doppler frequency shift for the purpose of detecting moving targets in the presence of clutter is Either an MTI radar or a pulse doppler radar. The distinction b/w them is based on the fact that in a Sampled measurement System like a pulse radar, ambiguities can arise in both the doppler frequency and the range measurements. Range ambiguities are avoided with a low sampling rate, and range measurement.

Range ambiguities are avoided with a low sampling rate and doppler frequency ambiguities are avoided with a high sampling rate, However in most radar applications the sampling rate, or prf can't be selected to avoid both types of measurement ambiguities. Therefore a compromise must be made and the nature of compromise generally determines wether the radar is called an MTI or a pulse doppler.

MTI usually refers to a radar in which the pulse repetition frequency is chosen low enough to avoid ambiguities in range, but with the consequence that the frequency measurement is ambiguous and result in blind speed.

The pulse doppler radar is more likely to use range-gate doppler filter banks than delay line-cancellers. Also a power amplifier such as a klystron is more likely to be used than a power oscillator like the magnetron. A pulse dopler radar operates at a higher duty cycle than does an MTI.

MTI FROM A MOVING PLATFORM

When a radar is in motion, as when mounted on a ship or an aircraft, the detection of a moving target in the presence of clutter is either an MTI radar or a pulse doppler radar. But it is not easy to detect the presence of target in such situation. The doppler frequency shift of the clutter is no longer at dc. It varies with speed of the radar platform, the direction of antenna in azimuth, and the angle of elevation to the clutter. Thus the clutter rejection notch needed to cancel clutter can't be fixed, but must vary. The design of MTI is more difficult with airborn radar than a shipborne radar because the higher speeds and the greater range of elevation angles result in a greater variation of the clutter spectrum

In addition to shifting the center frequency of the clutter, its spectrum is also widened. An approximate measure of the spectrum width can be found by taking the differential of the doppler frequency

$f_d = 2(v/\lambda)\cos\theta$

$$\Rightarrow \quad \Delta f_d = \frac{2v}{\lambda}\sin\theta\,\Delta\theta \qquad -(1)$$

$v \rightarrow$ plateform speed

Compensation for clutter doppler shift:- Two methods are used for compensation. In one implementation the frequency of coho is changed to compensate for the shift in clutter doppler frequency.

Compensation in some cases can also be made open loop by using the a priori knowledge of the velocity of the platform carrying the radar and the direction of the antenna pointing.

Compensation for clutter doppler spread:—

As shown in eqn (1) the spread in the clutter spectrum is a funcn. of angle α b/w the velocity vector of the moving platform and the antenna beam-pointing direction.

Compensation of clutter doppler spread is given by DPCA (Displaced Phase Center Antenna).

OTHER MTI DELAY LINES :→

MTI radar used acoustic delay lines in which EM signals were converted into acoustic waves. The acoustic signals were delayed, and then converted back into EM signals. The process was lossy (50 to 70 dB) of limited dynamic range, and spurious responses were generated that could be confused for legitimate echoes. Since acoustic waves travel with a speed about 10^{-5} that of EM waves, an acoustic line can be of practical size whereas an EM delay is not. However acoustic delay lines are larger ~~than~~ and heavier than digital lines and must usually be kept in a tempr.-controlled environment to prevent unwanted changes in delay time.